Increases in DXA-derived visceral fat across one season in professional rugby union players: importance of visceral fat monitoring in athlete body composition assessment.

Running Title: Seasonal changes to VAT in professional rugby

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Abstract

Introduction: In rugby, the average player body mass has increased by approximately 25% since 1955. Visceral adipose tissue (VAT) is associated with low grade inflammation, and chronic diseases, such as cardiovascular diseases. The purpose of this study was to investigate changes in VAT in relation to other indices of body composition, across one season in professional rugby.

Methodology: One hundred and sixteen male rugby union players' (age: 26.2 ± 4.6 y, BMI: 29.40 ± 3.22kg.m^2) total body composition dual energy X-ray absorptiometry scans from four time points across the season (baseline, pre-season, mid-season and post-season) were analysed. Players were grouped by playing position, forwards (n= 65) and backs (n= 51). Players followed individually tailored diet plans.

Results: Mean baseline VAT was 404.67 ± 229.43g (forwards: 469.36 ± 263.16g, backs: 311.40 ± 121.15g). Total mass, lean mass, body fat percentage (%BF) and VAT were greater in forwards than backs at all four timepoints. Meaningful increases in VAT across the season, were observed in 37.5% of backs and 53.6% of forwards. There was a positive linear relationship between lean mass and total mass, up to 116.04kg total mass. Beyond this threshold, lean mass accumulation reduced and %BF and VAT mass increased. There were significant relationships between %BF, VAT and BMI ($p < 0.001$), but no physiological relevant pattern was discerned.

Conclusions: Despite regular high-intensive exercise and individually tailored dietary control across a professional rugby season, players from both playing positions demonstrated increases in VAT, although the cause remains unknown. Our findings indicate the importance of monitoring VAT in athletes alongside standard measures of body composition. Additionally, our findings suggest there may be an upper threshold of body mass beyond which lean mass may not increase further and instead %BF and VAT are more likely to accumulate. Further research is required to identify how increasing player size may impact long-term cardiometabolic health given the known links between VAT and cardiometabolic risk.

Keywords: Visceral fat; Lean mass; Body composition; Dual-energy X-ray absorptiometry; Athletes.

Introduction

Rugby union is a field-based, contact team sport that is contested over 80 minutes which requires significant physiological demands from athletes [1]. Distinct physical differences exist between playing positions, forwards and backs. Rugby forwards tend to be taller, heavier, and have higher lean, fat and bone masses than backs [2]. The physical differences are relative to the playing demands associated with each position. Forwards predominately engage in static play, such as rucking and scrummaging, whereas backs perform more high-intensity running [3]. Since the introduction of professionalism in 1995, the average body mass of a professional rugby union player has increased steadily by approximately 25%, from 85kg to 105kg [4]. At the 2015 World Cup the average mass for backs and forwards was 91.5kg and 111.4kg, respectfully [5]. The average mass for forwards during the 2019 World cup was 114kg, the lightest forward weighing 80kg and the heaviest weighing 153kg [6]. Although athletes are typically perceived as a healthy cohort with exercise training providing important health benefits, risk factors, such as high body mass index (BMI), hypertension and unfavourable lipoprotein profiles have been reported in athletes where size underlies many of the sporting movements, such as National Football League (NFL) and rugby [7]. Most notably, retired linemen who have a large playing time body mass were found to have increased prevalence of cardiovascular disease (CVD) risk factors and risk of premature mortality [8].

Although the direct effect of body composition on performance in contact sports remains unclear, there is evidence for higher lean mass and lower fat mass at elite level [9]. This may reflect common assumptions that the power-to-weight ratio is optimised by increasing lean mass and curtailing fat mass [2]. Some research has reported that excess body fat may negatively impact performance by reducing speed, acceleration, thermoregulation, and endurance capacities by being negatively related to aerobic capacity [1]. However, few studies have examined changes that are specific to the type of body fat, in particular visceral adipose tissue (VAT).

Three studies have reported increases of total body fat percentage (%BF) and reductions in lean mass across the season in rugby players, despite no change in overall body mass [2, 10, 11]. However, these studies did not measure VAT. VAT is metabolically active and encompasses fat stores in the intra-abdominal pelvic region [12]. It is used as an indicator of metabolic health, given its strength in prediction of all-cause mortality, and associations with low grade, systemic inflammation [13] and CVD [14]. Differences in VAT and cardiometabolic risk factors have been found between rugby players of Polynesian and Caucasian descent, with Polynesian players displaying greater risk [15]. However, it remains unclear if players with increases in %BF across a season, have concomitant increases in VAT. VAT can be evaluated using dual energy X-ray absorptiometry (DXA), a technique which also measures three compartment body composition (fat, lean and bone masses) with high level precision [16]. Little is known about VAT in rugby players, which in non-athletic populations, is associated with an increased cardiometabolic risk. Therefore, the primary aim of this study was to investigate VAT and changes in VAT in relation to other indices of body composition, across one season in professional rugby union players. We hypothesised that %BF and VAT decreases and lean mass increases across the season with forwards exhibiting greater fat and lean masses than backs.

Materials and Methods

DXA scans (Lunar iDXA, GE Healthcare, Madison, Wisconsin, USA) of players from one professional rugby team measured at four time points, across one competitive season were analysed. DXA provides precise measurement of three compartment body composition [16], and is a preferred method of assessment in elite athletic populations [17]. DXA also provides an assessment of VAT and represents a useful tool for the evaluation of cardiometabolic risk [17].

Participants

The study sample included 116 professional male rugby union players from one European Rugby Championship Cup team. Players were categorised based on their primary playing position. Positional forwards (n= 65) were props, hookers, locks, and back rows. Positional backs (n= 51) were centres, scrum-halves, fly-halves, wingers and fullbacks. The age range of players was 18 to 39 years, and BMI ranged from 25 $kg.m^2$ to 41.5 $kg.m^2$. The mean BMI for forwards was 30.69 ± 3.36 $kg.m^2$ and for backs, 27.39 ± 1.43 $kg.m^2$. Ethical approval was provided by the Institution Research Ethics Committee. Additional approval and consent were obtained to access the pseudo-anonymised database from the host club. Participants provided prior written informed consent for use of their pseudo-anonymised data.

Methods

All players on the professional roster received a total body DXA assessment at four distinct time points throughout the competitive season [supplementary file: *baseline* (prior to pre-season) – June/July, *end of pre-season* – September, *mid-season* – November/December, and *post-season* – April/May]. Players were excluded from the analysis if they were missing more than two DXA scan time points. Standard scanning protocols were used to ensure maximum reliability [18]. Athletes were scanned early in the morning (7:00am to 9:00am), prior to food or fluid ingestion and exercise, in euhydrated state, and wearing minimal clothing [19]. One skilled technologist conducted and analysed all scans following the manufacturer's guidelines for patient positioning. This protocol was replicated for all scans. Athletes lay in a supine position on the DXA scanner bed and were positioned with hands in a fully pronated position with an approximate 5cm gap between hands and thigh. Athletes were instructed to remain in position until otherwise instructed. All scans were checked by a second skilled densitometrist, certified in clinical densitometry (International Society of Clinical Densitometry). Players' diet was not altered by this study however, diets were controlled by the team's lead nutritionist who designed individual diet plans specific to playing position demands and training days i.e. aerobic, resistance and rest. This individually tailored diet plan was reviewed regularly and manipulated throughout the season based on individual calorie requirements (supplementary file: Table 3).

Analyses of data were conducted using GE Lunar EnCore software (version 15.0) for total mass, lean mass and %BF, and the advanced CoreScan software (EnCore version 15.0, GE Lunar Healthcare, Madison, WI) for estimated VAT (g). The region of interest over the android region for the assessment of VAT was automated by the CoreScan software and VAT was determined using a validated model derived from DXA and computed tomography (CT) images by subtracting subcutaneous fat from total abdominal fat. Visceral fat derived from iDXA is validated against computed tomography and is highly correlated with criterion magnetic resonance imaging (MRI) measurements [20]. Visceral fat outcomes were compared to recently published athlete reference ranges for VAT measured by DXA [21]. Mellis et al. precision error data was used as a reference for VAT measurements [22].

Statistical Analysis

All analyses were carried out using 'R' version 3.6.1 (R Foundation for Statistical Computing, Vienna, Austria) [23]. Descriptive statistics were calculated as mean ± standard deviation (SD) for the team and by positional group. Data was deemed to be normally distributed. A standard linear model was used with normality assumption to determine the effect of position on trends in VAT and %BF over time. Scatterplots, linear regression and a standard test of slope were used to determine relationships between BMI, %BF and VAT for team and by positional group. A free-knot splines, a nonparametric smoothing and regression analysis, was used to investigate whether there was a threshold in total mass over which lean mass did not contribute. The package freeknotsplines was used with a degree one polynomial and one know [24]. The optimal knot point was determined using a least-squares fit. The performance of the least-squares splines is dependent upon the number and location of the knots or join points for the polynomial segments. A Bayesian analysis was included to establish bounds of uncertainty to identify a 95% posterior credible region of the estimated point of threshold. Clustering was used to investigate whether there were common patterns in VAT from baseline to post-season. The change in VAT between time measurement points were plotted for each player. These were then clustered using k-means clustering, having identified five clusters as the optimal number via the elbow method. A two-sample test of proportions of equality for proportion those who demonstrated increases in VAT was used to compare differences between playing positions. Individual changes in VAT between each time point were plotted and visually interpreted using Bland-Altman analysis.

Results

Table 1 presents mean ± SD for age, height, BMI, total mass, lean mass, %BF and VAT mass by playing position for the four time points.

The mean %BF for forwards and backs was 17.7% and 13.5%, respectfully. Between baseline and post-season, %BF decreased 2.2%, with a 0.9% reduction for forwards and 1.19% reduction for backs. Lean mass showed minimal change, remaining relatively consistent for both playing positions across the season. Forwards had higher VAT values at each time point compared to backs. Backs experienced a greater reduction in VAT across the season (-13.43g) (Table 1).

*****Insert Table 1*****

For the team, there were no significant changes in VAT across the season. The cluster analysis identified an increase from baseline to pre-season, decrease from pre-season to mid-season and a return to baseline values at post-season as the most common across season VAT pattern (Table 2). Of players who demonstrated increases in %BF across the season, 65.5% (n= 19) had concomitant increases in VAT and 34.5% had decreases in VAT (n= 10). Of players who demonstrated decreases in %BF across the season, 61.5% (n= 48) had concomitant decreases in VAT and 38.5% (n= 30) had increases in VAT.

****Insert Table 2****

No significant changes in group mean *VAT* [increase or decrease from baseline to pre-season (p= 0.79) or from baseline to post-season (p= 0.57)] were identified. Sub-group analyses by position indicated that 37.5% of backs and 53.6% of forwards had increases and 62.5% of backs and 46.4% of forwards had decreases in VAT across the season. A two-sample test of proportions of equality of proportion of backs and forwards who demonstrated increases in VAT gave a p-value equal to 0.06. There were no significant changes in group mean *%BF* [increase or decrease from baseline to post-season (p= 0.33)]. By position, 20.5% of backs and 23.6% of forwards had increases and 79.5% of backs and 76.4% of forwards had decreases in %BF across the season. There were no significant changes in group mean *lean mass* [increase or decrease from baseline to post-season (p= 0.82)]. By position, 64.1% of backs and 46.4% of forwards had increases and 35.9% of backs and 53.6% of forward had decreases in lean mass across the season. There were no significant changes in group mean *total mass* [increase or decrease from baseline to post-season (p= 0.10)]. By position, 40% of backs and 26.8% of forwards had increases and 60% of backs and 73.2% of forwards had decreases in total mass across the season. Analysis of individual changes in VAT indicated that four players (three forwards and one back) had a meaningful loss and four players had a meaningful increase in VAT (two forwards and two backs) between baseline and end of pre-season, according to Bland-Altman analysis. Between pre-season and mid-season, one player lost VAT and one player gained VAT (both backs). Between mid-season and post-season, two players lost VAT (one forward and one back) and three gained VAT (two forwards and one back) (Supplementary file: Figure 4).

Figure 1a presents the relationship between %BF and BMI for all players by position groups. A significant relationship was identified, although no meaningful pattern was discerned for all players or by playing position (R^2= 0.492). A significant relationship was identified between VAT and %BF, although no meaningful pattern was discerned for all players or by playing position (R^2= 0.216) (Figure 1b). A significant relationship was identified between VAT and BMI, although no meaningful pattern was discerned for all players or by playing position (R^2= 0.177) (Figure 1c). Figure 2 presents a positive linear relationship between lean mass and total mass. A significant breakpoint in the slope was identified. The optimal knot value was located at 116.04 kg of total mass and thereafter there was no longer direct positive relationships with lean mass. A Bayesian analysis was included to establish bounds of uncertainty and identified a 95% posterior credible region of the estimated pointed of threshold was between 111.22 kg to 122.03 kg with an estimated value of 116.04 kg (see supplementary files: Figure 5 and 6).

****Insert Figure 1 and 2****

Discussion

This study investigated changes in DXA-derived VAT in relation to other indices of body composition, across one season in professional rugby union players. We investigated possible inter-relationships of VAT with %BF, lean mass and BMI. The most significant findings included changes to player's VAT, irrespective of playing position, across the season fell into 5 main trends. The most common trend showed that VAT increased from baseline to pre-season, decreased from pre-season to mid-season and increased again from mid-season to post-season (Table 2). There were no associations between %BF or VAT and BMI, rejecting our hypothesis that VAT would display concomitant changes with %BF. A total body mass threshold (116.04 kg) was identified beyond which lean mass accumulation decreased and %BF and VAT increased (Figure 2). Despite the relative changes in body composition, there were no significant changes in the mass of players over the season which aligns with previous research [10, 11, 2].

Forwards were found to have greater levels of VAT and a more varied distribution compared to backs at each time point. Positional groups demonstrated no significant changes in %BF from baseline to post-season (Forwards: -0.81%, Backs: -1.19%). Importantly, individual change analysis [16] revealed that forwards had a greater tendency to have a reduction in lean mass between baseline and post-season compared to backs. Forwards and backs had a similar tendency to have decreased %BF at post-season. However, forwards had a greater propensity to have increased VAT at post-season. This finding, therefore, refutes our hypothesis that players, regardless of playing position would exhibit a decrease in %BF and VAT, and an increase in lean mass across the season. According to established data, our cohort of players, forwards and backs, categorise as 'overweight and obese', with an estimated precision error for VAT mass of 43.7g [22]. The Bland-Altman analysis revealed that four players had VAT outside the limits of agreement (see supplementary file: Figure 4). Moreover, all four players categorised as forwards and had a total mass greater than 116.04 kg, the total mass threshold for lean mass accumulation.

Cluster analysis identified 5 main function group changes to VAT across the season (Table 2). The most common trend was decreased VAT from baseline to mid-season before returning to baseline values at post-season. This coincided with changes to lean mass and

%BF suggesting, fat mass gains precede losses in lean mass [11]. Potential rationale for the most common across season trends in VAT, include a shift in training focus during the latter stage of the season, a reduction in duration and frequency of gym-based training sessions and a reduction in competitive demands towards the end of the season, opposed to pre-season [10, 11, 2]. Furthermore dietary and nutritional factors [25] or the occurrence of injuries preventing the engagement in training load may potentially impact changes to VAT. [10, 26]. The rugby institution where our research was conducted, adopts a comprehensive load monitoring programme that maintains training load (albeit modified) during injury, suggesting that this factor will not have affected our findings. Interestingly, mean %BF decreased between baseline and mid-season and increased at post-season but remained lower than baseline values, falling in line with previous research [10, 11, 2].

Zemski et al. reported that Polynesian players had a significantly higher VAT than Caucasian players (771 ± 609 cm^3 vs 424 ± 235 cm^3) [15]. Visceral fat values were compared to recently published athlete reference ranges measured by DXA [21]. Compared to the general population, who were greater in age, our cohort had lower mean VAT (Rugby: 404.67 ± 229.43 g, General population: 570 g)[21]. However, compared to the athletic population, who were similar in age, our cohort had greater mean VAT (Rugby: 404.67 ± 229.43 g, Athletic Population: 337 g) [21]. When compared to the VAT mass percentiles (g) for adult males and male athletes, mean values for all players fell on the 50th percentile range for both, where being nearer to the 1st percentile is desirable [21]. For cardiovascular health, elevated measures of body composition during playing career has a clinical relevance. NFL players with increased body mass during their playing career have been reported to present with increased lipid profiles, prevalence of subclinical atherosclerosis and cardiometabolic risk [8].

There was a significant relationship ($p < 0.001$), but no association ($R^2 = 0.216$) identified between %BF and VAT, rejecting the study hypothesis (Figure 1). Although there were minimal reductions to %BF, this is not reflected in VAT values. Importantly, this suggests that low levels of VAT cannot be assumed based on a low %BF. Similar to Bosch et al., accumulation occurred at different thresholds for players [27]. It is possibly indicative that excess fat is distributed as subcutaneous adipose tissue before being stored as VAT [27], however, without analysing player's metabolism this is merely speculative. It has been previously reported that 37% of athletes in elite rugby union have VAT above the threshold for increased cardiometabolic risk [28]. Although there was no association between players BMI and VAT, larger players had higher VAT, consistent with findings from previous research [17]. There are distinct differences in physical demands between positions, for backs, higher loads of dynamic activity, such as high intensity running and long-distance running, and forwards, short repetitive bursts of static activities, such as rucking, mauling and scrummaging [3]. Therefore, providing plausible justification for the significant differences in body composition. Furthermore, it is possible that the physical demands associated with the forward position, such as high levels of impact and collision, benefit from the protective qualities associated with higher levels of %BF and thus VAT [29]. There does not appear to be a direct relationship between BMI and VAT (Figure 1c). However, as %BF increased, there was moderate positive linear relationship with VAT, largely for forwards (Figure 1a).

It remains unknown if there is an upper limit by which lean mass in athletes does not increase further. Our findings suggest that a threshold may exist when total body mass reaches 116.04 kg, and further mass accumulation is fat mass (Figure 2). In this cohort, the optimal knot value was located at 116.04 kg, before this point increases in total mass are resultant of increases in lean mass and not fat tissue. However, after this point increases in total mass are not directly related to lean mass. The posterior plot indicates a 95% posterior credible region that total mass threshold for lean mass accumulation falls between 111.22 kg to 122.03kg with an estimated value of 116.04 kg (see supplementary files: Figure 5 and 6). This provides strength of evidence for the total mass threshold beyond which a player will not accumulate lean mass at the same rate, therefore mass gained beyond this is due to fat mass. This finding supports Bosch et al. who found that increases in NFL players body mass beyond 114 kg was due to fat mass accumulation and not lean mass [27]. Furthermore, Abe et al., reported that fat-free mass in athletes increased linearly up to 90 kg and skeletal muscle mass increased in a parabolic fashion before plateauing (17 kg/m2) beyond 120 kg body mass [30]. This is the first study to demonstrate a possible upper limit of lean mass accumulation in male rugby union players and is of concern given the speculation of increasing player size. Although mean values for lean mass can vary by playing position, the magnitude of difference between playing positions is between 4.9% and 5.1%. Conversely, average %BF and VAT values have a much greater variance of distribution (Figure 1). To date, there is no clear evidence to support an optimal lean mass value in athletes. In addition to negatively impacting performance [1], VAT is an independent risk factor for CVD, insulin resistance and dysfunctional lipid metabolism and glucose [31].

Our study is limited in that no formal hydration assessment was performed on players prior to testing, therefore euhydration was assumed on the basis of self-report. We did not correlate changes in body composition with fitness, rugby-specific tests or with other cardiovascular risk factors, therefore inference, cannot be made on the impact of changes to cardiovascular status or playing performance. Adherence to the individually tailored nutritional programmes is assumed.

Our findings suggest that despite known advantages for forwards to have greater mass, total mass accumulation beyond 116 kg potentially leads to greater fat mass accumulation. Decreases in %BF do not necessarily reflect changes to VAT and reduction may be caused by subcutaneous fat loss. If low levels of VAT cannot be assumed based on low %BF, we recommend that DXA-monitoring of body composition to include analysis of VAT. Future research is required to identify measures, such as diet and training that may limit VAT accumulation while increasing player size for performance and to establish a players cardiometabolic health where deliberate mass gain is present to include VAT, given the known presence of CVD risk factors such as, hypertension and unfavourable lipoprotein profiles.

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Figure Legends

Figure 1. Scatter plots by position group: (A) body fat percentage v BMI, (B) Visceral fat v body fat percentage, and (C) Visceral fat v BMI.

Figure 2. Relationship between lean mass and total mass with the optimal knot value located at 116.04 kg total mass.

Table 1: *Anthropometric and total three-compartment body composition by playing position.*

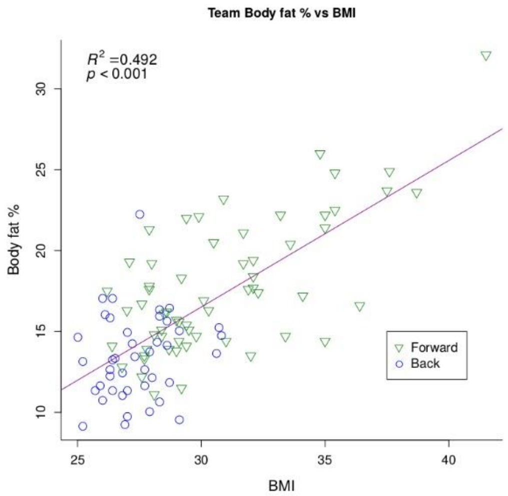
	Forwards				**Backs**			
	Baseline	**Pre-season**	**Mid-season**	**Post-season**	**Baseline**	**Pre-season**	**Mid-season**	**Post-season**
Age (yrs)	26.5 ± 4.5				25.6 ± 4.3			
Height (cm)	189.42 ± 7.4				183.12 ± 5.7			
BMI	30.69 ± 3.35	30.68 ± 3.25	30.80 ± 3.16	30.31 ± 4.33	27.39 ± 1.43	27.25 ± 1.41	27.12 ± 1.30	27.07 ± 1.37
Total mass (kg)	109.73 ± 9.57	110.06 ± 9.32	109.89 ± 8.58	108.59 ± 8.80	91.81 ± 8.06	91.57 ± 7.52	90.98 ± 7.80	86.81 ± 18.84
Lean mass (g)	85.61 ± 5.94	86.38 ± 6.05	87.36 ± 5.48	85.64 ± 5.76	75.22 ± 6.65	75.77 ± 6.46	76.15 ± 6.68	74.73 ± 6.96
Body fat (%)	17.71 ± 4.06	17.18 ± 3.95	16.26 ± 3.89	16.90 ± 4.20	13.47 ± 2.61	12.68 ± 1.98	11.73 ± 2.08	12.28 ± 2.02
Visceral fat (g)	469.36 ± 263.16	462.81 ± 244.85	462.73 ± 225.44	467.79 ± 269.85	311.40 ± 121.15	299.50 ± 116.94	296.95 ± 125.50	297.96 ± 119.02

Data are presented as mean ± SD. BMI - body mass index.

Table 2: Clustering in VAT patterns.

Cluster	**No. Players**	**BMI**	**%BF**	**Base-Pre**	**Pre-Mid**	**Mid-Post**
1	15	29.4	15.5%	+	-	+
2	13	28.6	14.4%	-	=	+
3	13	30.2	15.7%	+	=	-
4	13	31.4	17.2%	-	+	-
5	1	30.5	20.5%	-	-	+

The five clusters representing changes in visceral fat across a season; Cluster 1: Baseline to pre-season: increase; pre-season to mid-season: decrease; mid-season to post-season: increase; Cluster 2: baseline to pre-season: decrease; pre-season to mid-season: equivalent; mid-season to post-season: increase; Cluster 3: baseline to pre-season: increase; pre-season to mid-season: equivalent; mid-season to post-season: decrease; Cluster 4: baseline to pre-season: decrease; pre-season to mid-season: increase; mid-season to post-season: decrease; Cluster 5: baseline to pre-season: decrease; pre-season to mid-season: decrease; mid-season to post-season: increase.



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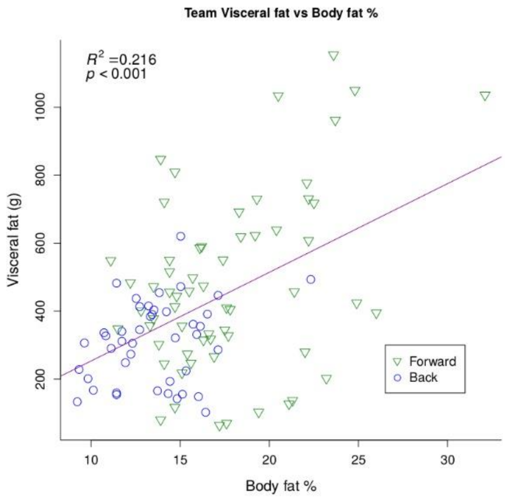
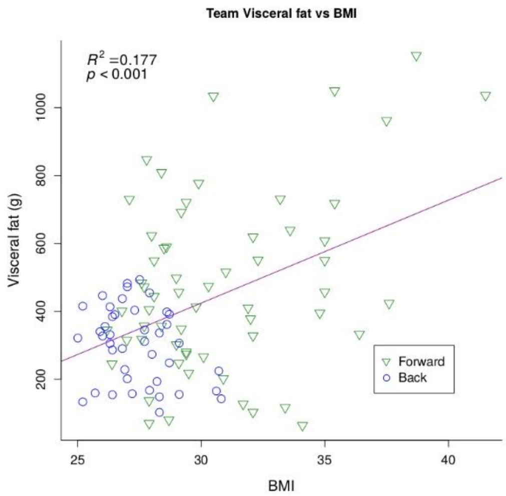


B



C

Figure 1: Scatter plots by position group: (A) body fat percentage v BMI, (B) Visceral fat v body fat percentage, and (C) Visceral fat v BMI.

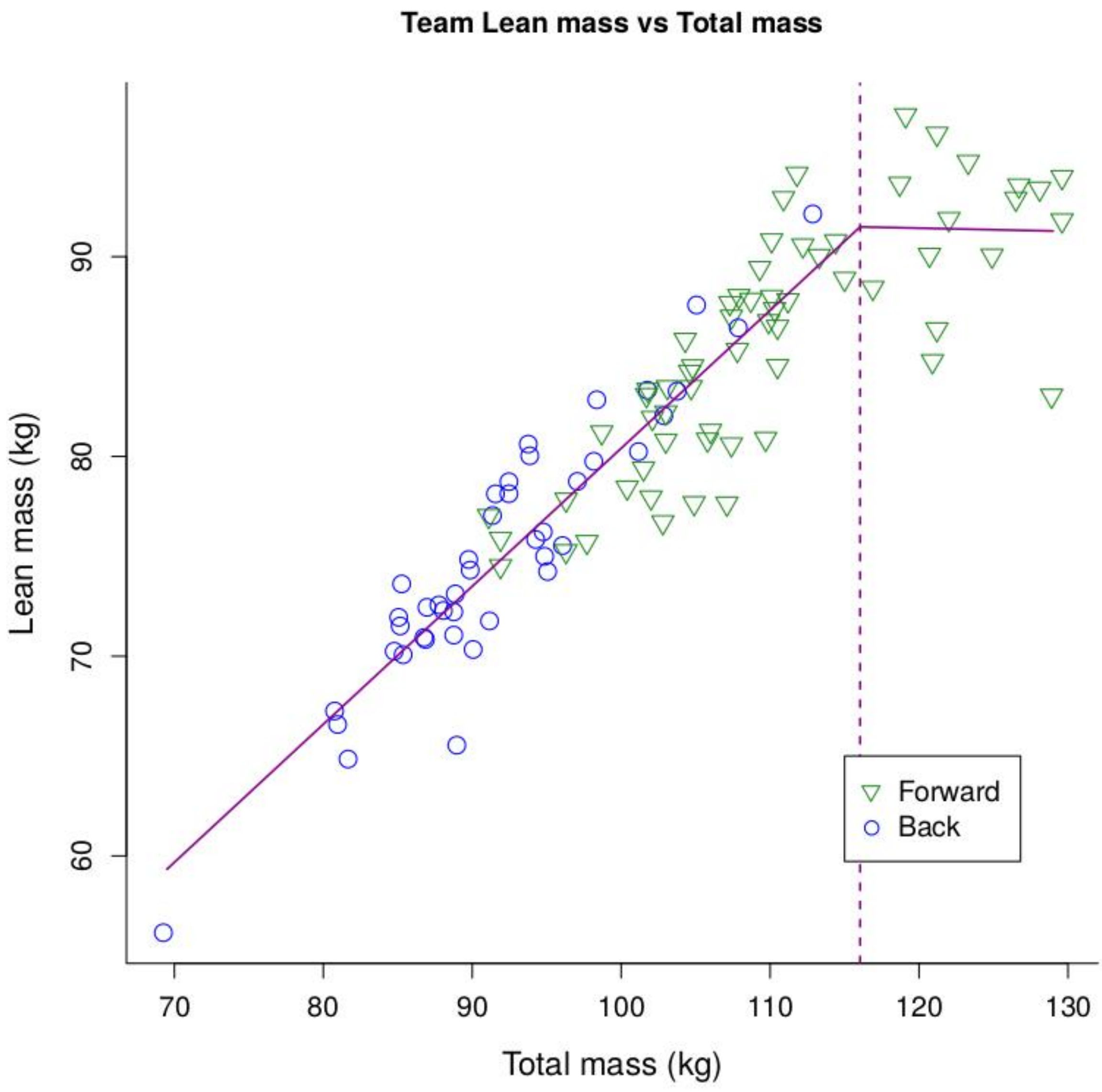


Figure 2: Relationship between lean mass and total mass with the optimal knot value located at 116.04 kg total mass.

Supplementary files

Table 3. Daily energy and macronutrient targets for the athletes on training days vs recovery days.

Energy needs:

- BMR = 10 x weight (kg) + 6.25 x (cm) – 5 x age (years) + 5 =
- Very active (hard exercise/sports 6-7 days a week): 1.76
- Calorie-Calculation = BMR x 1.76
- Daily average energy needs: calories daily

	Training day pitch	Training day gym	Active recovery
Carbohydrate	6g kg BM	4g per kg BM	3-4g per kg BM
Protein	1.7-2.0g kg BM daily	1.7-2.0g kg BM daily	1.7-2.0g kg BM daily
Fat	0.7-1.2g kg BM daily	0.7-1.2g kg BM daily	0.7-1.2g kg BM daily

Abbreviations: BMR - basal metabolic rate; BM - body mass.

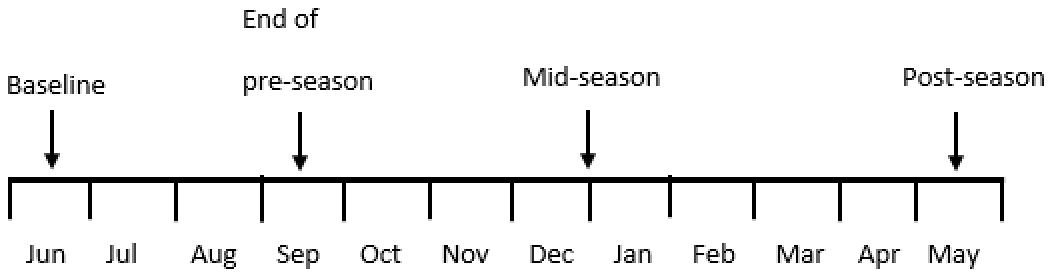


Figure 3. Timeline of DXA scan assessment.

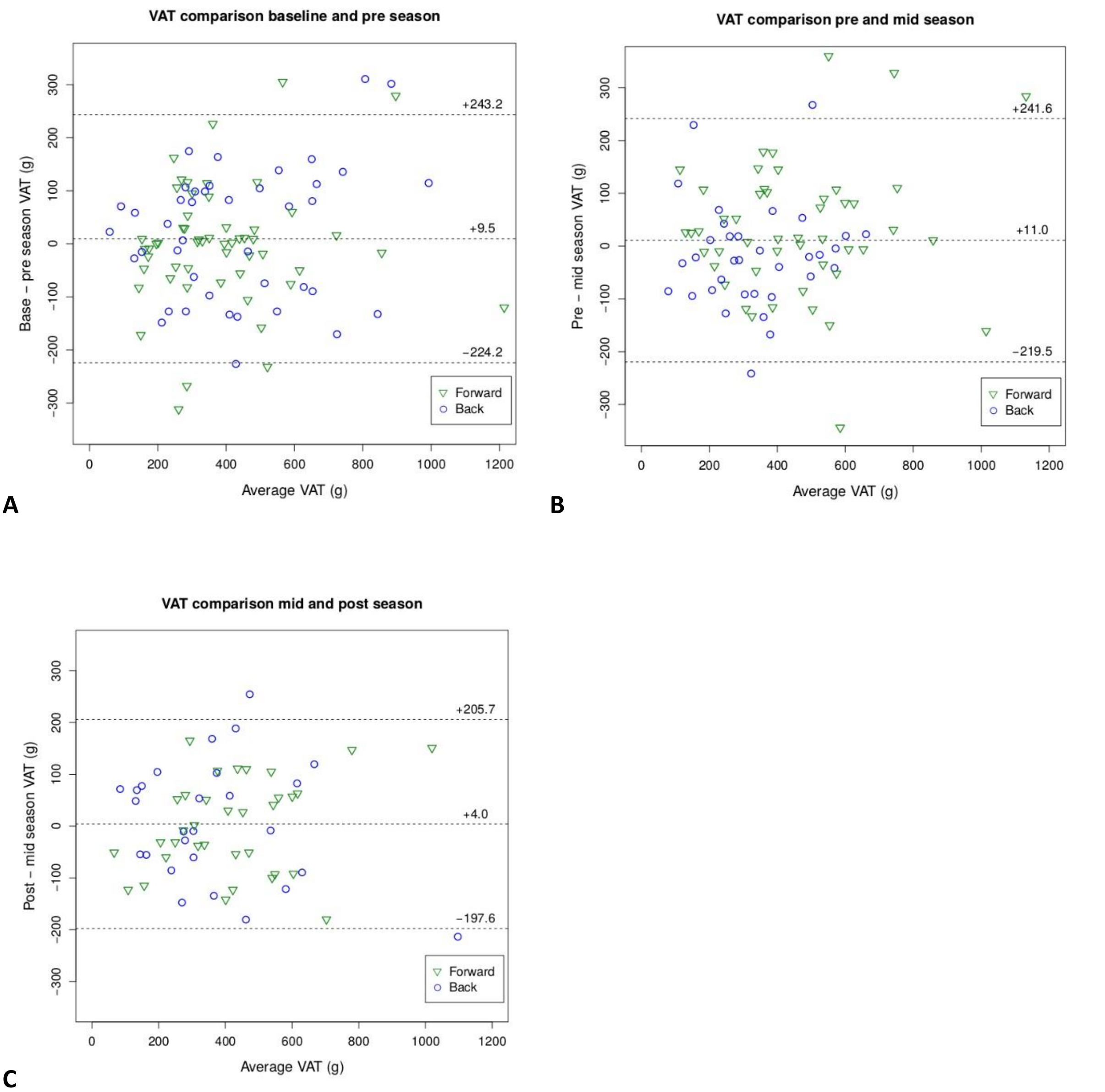


Figure 4. Bland-Altman analysis of VAT changes across the season: (A) VAT comparison between baseline and end of pre-season, (B) VAT comparison between end of pre-season and mid-season, and (C) VAT comparison between mid-season and post-season.

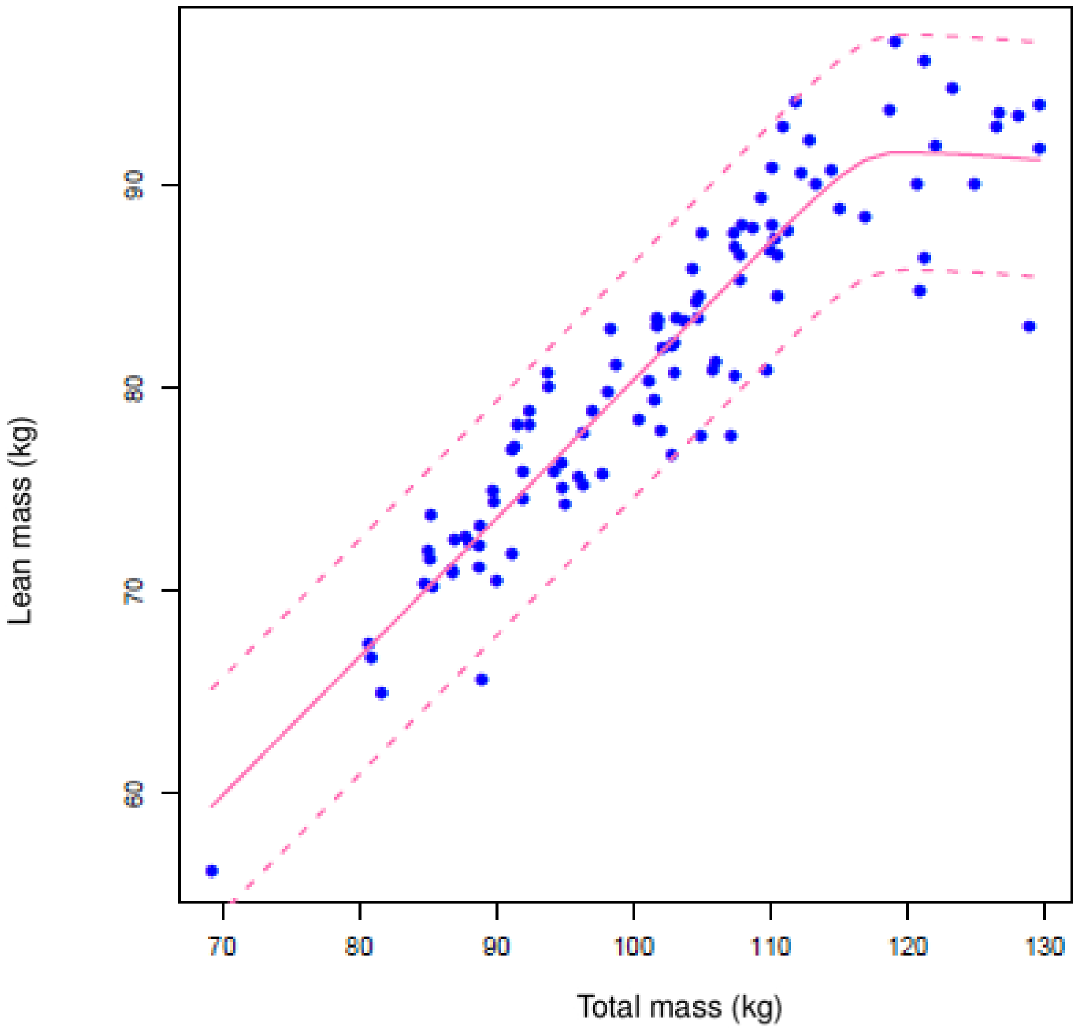


Figure 5. Scatter plot Bayesian analysis of relationship between lean mass and total mass with the optimal knot value located at 116.04 kg total mass.

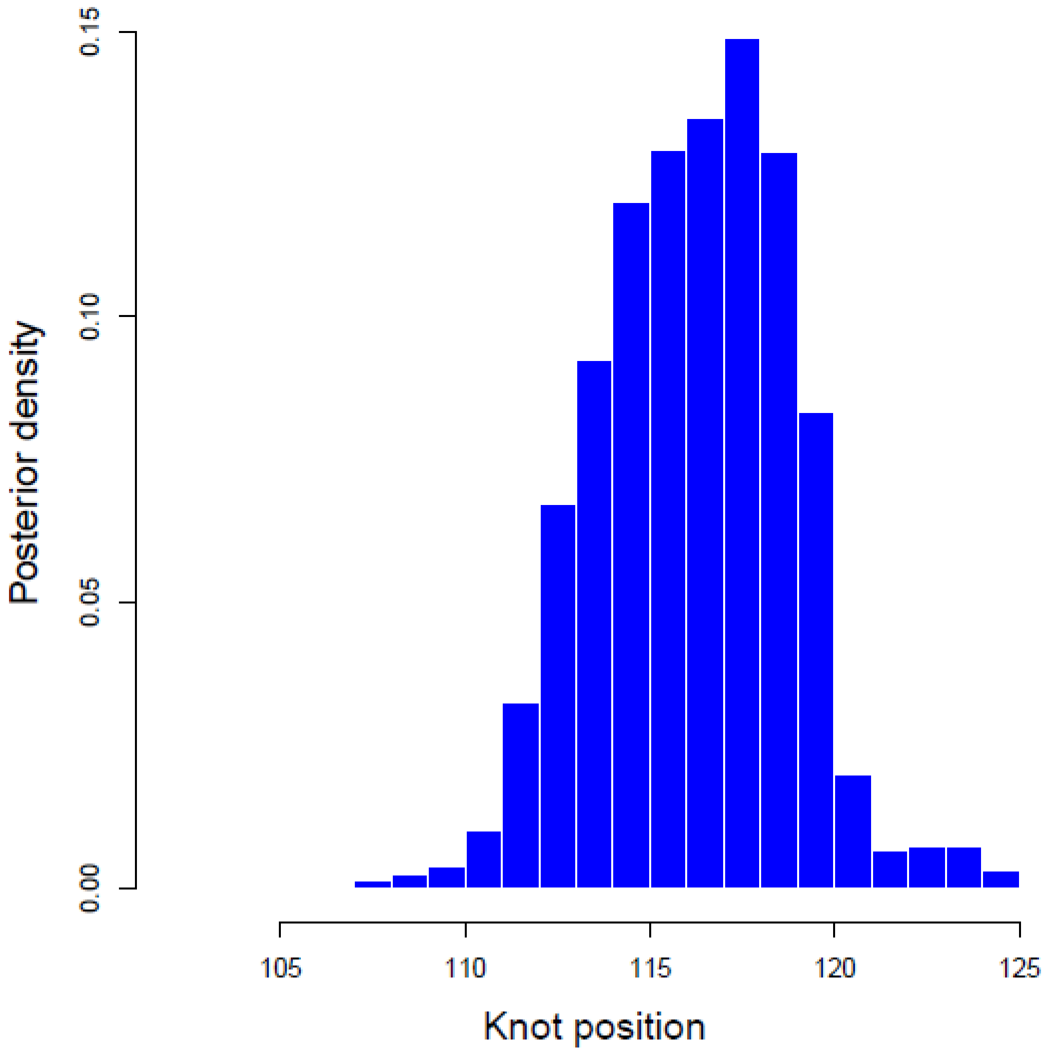


Figure 6. Posterior plot indicating a 95% posterior credible region that total mass threshold for lean mass accumulation falls between 111.22kg to 122.03kg with an estimated value of 116.04kg.